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OPTICAL APPARATUS WITH FARADAY ROTATOR, STATIC GAIN FLATTENING FILTER AND VARIABLE OPTICAL ATTENUATOR

Cross-Reference to Related Applications

This application is a continuation-in-part of serial no. 09/801,566, filed March 7, 2001 and identified as attorney docket 21501-731, which is a continuation-in-part of serial no. 09/765,971 filed 01/19/2001 which is a continuation-in-part of serial no. 09/729,661 filed 12/04/2000, which is a continuation-in-part of serial no. 09/666,763 filed 09/21/2000, which application is a continuation-in-part of and claims the benefit of priority from Provisional Patent Application Serial No. 60/206,767, filed 05/23/2000, serial no. 09/666,763 also being a continuation in part of serial no. 09/571,092 filed 5/15/2000, which is a continuation of serial no. 09/425,099 filed 09/23/1999, which is a continuation-in-part of serial no. 09/022,413 filed 02/12/1998, which claims priority to KR 97-24796 filed 06/06/1997, all of which applications are fully incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to devices for transmitting optical signals, and more particularly to static filters and Faraday rotators.

Description of Related Art

In modern telecommunication systems, many operations with digital signals are performed on an optical layer. For example, digital signals are

optically amplified, multiplexed and demultiplexed. In long fiber transmission lines, the amplification function is performed by Erbium Doped Fiber Amplifiers (EDFA's). The amplifier is able to compensate for power loss related to signal absorption, but it is unable to correct the signal distortion caused by linear dispersion, 4-wave mixing, polarization distortion and other propagation effects, and to get rid of noise accumulation along the transmission line. For these reasons, after the cascade of multiple amplifiers the optical signal has to be regenerated every few hundred kilometers. In practice, the regeneration is performed with electronic repeaters using optical-to-electronic conversion. However to decrease system cost and improve its reliability it is desirable to develop a system and a method of regeneration, or signal refreshing, without optical to electronic conversion. An optical repeater that amplifies and reshapes an input pulse without converting the pulse into the electrical domain is disclosed, for example, in the U.S. Pat. No. 4,971,417, Radiation-Hardened Optical Repeater". The repeater comprises an optical gain device and an optical thresholding material producing the output signal when the intensity of the signal exceeds a threshold. The optical thresholding material such as polydiacetylene thereby performs a pulse shaping function. The nonlinear parameters of polydiacetylene are still under investigation, and its ability to function in an optically thresholding device has to be confirmed.

Another function vital to the telecommunication systems currently performed electronically is signal switching. The switching function is next to be performed on the optical level, especially in the Wavelength Division Multiplexing (WDM) systems. There are two types of optical switches currently under consideration. First, there are wavelength insensitive fiber-to-fiber switches. These switches (mechanical, thermo and electro-optical etc.) are dedicated to redirect the traffic from one optical

fiber to another, and will be primarily used for network restoration and reconfiguration. For these purposes, the switching time of about 1 msec (typical for most of these switches) is adequate; however the existing switches do not satisfy the requirements for low cost, reliability and low insertion loss. Second, there are wavelength sensitive switches for WDM systems. In dense WDM systems having a small channel separation, the optical switching is seen as a wavelength sensitive procedure. A small fraction of the traffic carried by specific wavelength should be dropped and added at the intermediate communication node, with the rest of the traffic redirected to different fibers without optical to electronic conversion. This functionality promises significant cost saving in the future networks. Existing wavelength sensitive optical switches are usually bulky, power-consuming and introduce significant loss related to fiber-to-chip mode conversion. Mechanical switches interrupt the traffic stream during the switching time. Acousto-optic tunable filters, made in bulk optic or integrated optic forms, (AOTFs) where the WDM channels are split off by coherent interaction of the acoustic and optical fields though fast, less than about 1 microsecond, are polarization and temperature dependent. Furthermore, the best AOTF consumes several watts of RF power, has spectral resolution about 3 nm between the adjacent channels (which is not adequate for current WDM requirements), and introduces over 5 dB loss because of fiber-to-chip mode conversions.

Another wavelength-sensitive optical switch may be implemented with a tunable Fabry Perot filter (TFPF). When the filter is aligned to a specific wavelength, it is transparent to the incoming optical power. Though the filter mirrors are almost 100% reflective no power is reflected back from the filter . With the wavelength changed or the filter detuned (for example, by tilting the back mirror), the filter becomes almost totally reflective. With the optical circulator in front of the filter, the reflected

power may be redirected from the incident port. The most advanced TFPF with mirrors built into the fiber and PZT alignment actuators have only 0.8 dB loss. The disadvantage of these filters is a need for active feedback and a reference element for frequency stability.

A VOA is in opto-mechanical device capable of producing a desired reduction in the strength of a signal transmitted through a optical fiber. Ideally, the VOA should produce a continuously variable signal attenuation while introducing a normal or suitable insertion loss and exhibiting a desired optical return loss. If the VOA causes excessive reflectance back toward the transmitter, its purpose will be defeated.

Although fixed band-rejection filters are readily available using Bragg or long-period gratings impressed into the core of an optical fiber there are no simple, adjustable all-fiber band-rejection filters. Such filters would vary the amplitude of signals within a fixed wavelength range. Although a variable transmission band-rejection filter of sorts can be made by varying the center wavelength of a Bragg or long-period grating, as one channel is attenuated another channel is unavoidably strengthened.

Accordingly, there is a need for an improved optical apparatus that includes a Faraday rotating mirror and a fixed, static gain flattening filter in order to reduce the required tuning range of band-rejection filters. There is a further need for an optical apparatus with a variable broadband attenuator that is used to reduce the tuning range of band-rejection filters.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an optical apparatus that provides for a reduction in the required tuning range of band-rejection filters.

Another object of the present invention is to provide an optical apparatus that includes a variable broadband attenuator to reduce the tuning range of band-rejection filters.

A further object of the present invention is to provide an optical apparatus that includes a static filter, a Faraday rotator and a reflector to create a reflected signal used to improve the performance of tunable band-rejection filters.

A further object of the present invention is to provide an optical apparatus that includes a static filter, a Faraday rotator, a variable optical attenuator and a reflector to create a reflected signal used to improve the performance of tunable band-rejection filters.

These and other objects of the present invention are achieved in an optical apparatus for transmitting an optical signal that includes a static filter, a Faraday rotator and a reflector. The Faraday rotator makes a first change in polarization of an optical signal in a first direction, and a second change in polarization of the optical signal received from the reflector in a second direction. This produces a polarization of the optical signal that is substantially orthogonal to an initial polarization state of the optical signal.

In another embodiment of the present invention, an optical apparatus for transmitting an optical signal includes a static filter, a Faraday rotator, a variable optical attenuator that attenuates at least a portion of the optical signal and a reflector. The Faraday rotator makes a first change in polarization of the optical signal received in a first direction, and a second change in polarization of the optical signal received from the reflector in a second direction. This produces a polarization of the optical signal that is substantially orthogonal to an initial polarization state of the optical signal.

In another embodiment of the present invention, an optical apparatus for transmitting an optical signal includes a static filter, a Faraday rotator and a reflector positioned along a first optical path defined by the static

filter, the Faraday rotator and the reflector. The reflector reflects at least a portion of the optical signal back in a direction towards the Faraday rotator along an optical path that is not the first optical path. The Faraday rotator makes a first change in polarization of the optical signal received from the static filter, and a second change in polarization of the optical signal received from the reflector. This produces a polarization of the optical signal that is substantially orthogonal to an initial polarization state of the optical signal.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a schematic view of an embodiment of an optical apparatus of the present invention that includes a static filter, Faraday rotator and a reflector.

Figure 2 is a schematic view of an embodiment of an optical apparatus of the present invention that includes a static filter, Faraday rotator, variable optical attenuator and a reflector.

Figure 3 is a schematic view of an embodiment of an optical apparatus of the present invention similar to Figure 1 but with the reflector positioned at an angle θ relative to a first optical path of the apparatus.

Figure 4 is a schematic diagram of one embodiment of a acousto-optic tunable filter type of mode coupler suitable for use with the Figures 1, 2 and 3 embodiments.

Figure 5 is a schematic diagram of one embodiment of an multiple mode coupler apparatus that can be coupled to the optical apparatus of Figures 1, 2 and 3.

DETAILED DESCRIPTION

Referring now to Figure 1, one embodiment of the present invention is an optical apparatus 10 for transmitting an optical signal that includes a

static filter 12 and a Faraday rotator 14. A reflector 16 is included and can be positioned adjacent to Faraday rotator 14. Faraday rotator 14 makes a change in polarization of an optical signal received in a forward direction and another change in the polarization of the optical signal after it is received from reflector 16 in a reverse direction to the forward direction. This produces a reflected polarization of the optical signal that is substantially orthogonal to an input polarization state of the optical signal. The orthogonally reflected polarization state is used to average out any polarization dependent loss that the input signal experiences before reach Faraday rotator 14. Due to manufacturing errors in Faraday rotator 14 and wavelength and temperature dependence of Faraday rotation angle, substantially orthogonal means plus or minus 20%, more preferably 10%, and still more preferably 5% from the true orthogonal state.

Static filter 12 can be, an interference filter, a fiber based filter a waveguide filter and include dielectric films and a transparent substrate. Faraday rotators are used in isolators and circulators and are well known in the art. In one embodiment, Faraday rotator 14 includes a garnet faced crystal placed in a magnetic field. Faraday rotator 14 preferably has a nominally 45° rotation for linear polarization in a single pass. For a double pass, the linear polarization is nominally 90° rotation.

Optical apparatus 10 can be combined with one or more optical devices, including but not limited to dynamic gain flattening filters, band-rejection filters, sensors and the like, to reduce the polarization dependent loss of the optical device by sending an input signal forward in the optical device, and then returning in a backward direction.

An optional lens 18 is provided to re-image the optical signal back into an optical fiber 20. Suitable lenses 18 include but are not limited to graded index lenses, micro-lenses and the like. Lens 18 can be positioned

between, optical fiber 20 and static filter 12, static filter 12 and Faraday rotator 14, or Faraday rotator 14 and reflector 16.

Reflector 16 is a high reflector that reflects at least 50% of incident light. High reflectivity mirrors are typically fabricated using metal or multi-layer dielectric coatings.

Optical fiber 20 can be a birefringent or non-birefringent single mode optical fiber or a multi-mode fiber. Optical fiber 20 can have various modes traveling within the fiber such as core modes, cladding modes, and polarization preserving modes. Optical fiber 20 can provide fundamental and cladding mode propagation along a selected length of optical fiber 20. Optical fiber 20 can be a pig-tail that optically connects to other optical fibers. These other optical fibers can be used to perform optical processing functions such as those found in band-rejection filters and the like.

Figure 2 illustrates another embodiment of the present invention that includes a variable optical attenuator (VOA) 22 which attenuates at least a portion of the optical signal. In one embodiment VOA 22 attenuates from 0 to 40 dB, and more preferably 0 to 10 dB. For example, a VOA placed at the mid-stage of an EDFA typically requires a 0 to 10 dB attenuation range. VOA 22 can VOA 22 can be positioned between, static filter 12 and Faraday rotator 14, Faraday rotator 14 and reflector 16 and lens 18 and static filter 12.

Referring now to Figure 3, static filter 12 and Faraday rotator 14 define a first optical path 24. Reflector 16 is positioned along an input optical path 24 at an angle θ. At angle θ, at least a portion of the optical signal received along the optical path 24 is directed along a second optical path 26. By tuning the angle θ the reflected power directed along the input optical path 24 can be varied to realize a VOA.

Numerous optical devices can be coupled to optical fiber 20 including but not limited optical processing components that effect the

condition of the optical signal. In one embodiment, the optical device is a mode coupler 28. Mode coupler 28 is configured to introduce a mechanical or index deformation of a portion of the optical fiber 20, and create perturbations in the optical modes in fiber 20 and provide a coherent coupling between two modes. Mode coupler 28 can couple a core mode to a cladding mode, one core mode to a different core mode and one cladding mode to a different cladding mode Suitable mode coupler's 28 include AOTF's, acoustic gratings, UV gratings, bending gratings and stress induced gratings as disclosed in serial no. ____________ filed 03/07/2001 and identified as attorney docket no. 21501-731 and serial no. 09/765,971 filed 01/19/2001, fully incorporated herein.

In one embodiment, illustrated in Figure 4, mode coupler 28 is an AOTF that includes an acoustic wave propagation member 30 and an acoustic wave generator 32. Acoustic wave generator 32 can produce multiple acoustic signals with individual controllable strengths and frequencies. Each of the acoustic signals provides a coupling between different modes traveling within optical fiber 20. A wavelength of an optical signal coupled between two different modes traveling within optical fiber 20 can be changed by varying the frequency of a signal applied to acoustic wave generator 32. Additionally, an amount of an optical signal coupled between two different modes traveling within optical fiber 20 can be changed by varying the amplitude of a signal applied to acoustic wave generator 32.

Referring now to Figure 5, a second AOTF mode coupler 34 is coupled to mode coupler 28. A circulator is coupled to second AOTF mode coupler 34. Delays 38 and 40 can also be included.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms

disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is: